

U. S. GOVERNMENT PRINTING OFFICE  
1918-1919

MAILED

TECHNICAL NOTES

SEP 29 1928

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TO: *Library, L.M.A.L.*

No. 298

THE DETERMINATION OF SEVERAL SPRAY CHARACTERISTICS OF  
A HIGH-SPEED OIL ENGINE INJECTION SYSTEM WITH AN OSCILLOSCOPE

By Chester W. Hicks and Charles S. Moore  
Langley Memorial Aeronautical Laboratory

**FILE COPY**

U. S. GOVERNMENT PRINTING OFFICE  
WASHINGTON, D. C.  
1918-1919

Washington  
September, 1928



3 1176 01425 6284

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL NOTE NO. 298.

THE DETERMINATION OF SEVERAL SPRAY CHARACTERISTICS OF  
A HIGH-SPEED OIL ENGINE INJECTION SYSTEM WITH AN OSCILLOSCOPE.

By Chester W. Hicks and Charles S. Moore.

S u m m a r y

This investigation was conducted at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics, in connection with the general research on aircraft type oil engines. The purpose of this investigation was to determine the injection lag, duration of injection, and spray start and cut-off characteristics of a fuel injection system operated on an engine and injecting fuel into the atmosphere.

A cam-operated fuel injection pump and a centrifugal type, spring-loaded, automatic injection valve were used to inject fuel into a light-tight compartment where the spray was observed with the aid of an oscilloscope. The spray image observed could be varied through all phases of the injection cycle by means of an adjustment of the oscilloscope breaker mechanism. A calibration of the oscilloscope made it possible to determine the engine crank angle corresponding to the spray phase under observation.

The effects of varying the engine speed from 400 to 1800 R.P.M., at a constant fuel quantity, and of varying the fuel

quantity from approximately one-half load to full load fuel quantity, at a constant engine speed, on the discharge characteristics of an automatic injection valve and fuel injection system were determined.

The injection lag in crank degrees was found to decrease with increase of engine speed at a constant fuel quantity, but remained constant for variable fuel quantities injected at constant engine speed. The duration of injection in crank degrees increased with an increase of either engine speed or fuel quantity. It was found that the oscilloscope was easily adapted to permit the investigation of an injection valve and fuel injection system when operated on an engine and injecting into the atmosphere.

### Introduction

The successful development of fuel injection systems for high-speed oil engines requires a thorough study of the operating characteristics of the systems under actual engine conditions. In the analysis of the combustion cycle of a given oil engine, it is of importance to know the time at which the fuel oil is injected into the combustion chamber of the engine, since the time of ignition of the fuel charge varies with the time of injection. The theoretical calculation of injection lag, time of injection, and fuel spray duration for an injection system is a difficult problem, because of the large number of variables

which must be taken into consideration. If the injection lag and spray duration of a given fuel injection system are determined by observations of single fuel sprays discharged into the atmosphere or into a pressure chamber, the results will not be comparable to those of engine operation, because the characteristics of the fuel injection system change with engine speed. It is desirable, therefore, to have a method of determining, for operating engine speeds, the injection lag, time of spray start and cut-off, and spray characteristics of a given fuel injection system.

Considerable information has been obtained on the characteristics of single fuel sprays (Reference 1). There is little information available, however, on the characteristics of successive fuel sprays discharged from an injection system operated at the speeds required for its use on a high-speed oil engine. Injection lag and duration, spray penetration and volume growth have been determined by ultra high-speed photography of single sprays injected into a chamber containing air under pressure (Reference 2). Information on injection lag and spray duration has also been obtained by recording the outline of sprays discharged onto moving targets (References 3 and 4). The stroboscope, "Stroborama," and oscilloscope have been used as means for observing the start of fuel injection, the shape and atomization of the fuel spray, and the spray cut-off (References 5, 6, and 7). The oscilloscope, as used in this investigation, made possible

the determination of the start and cut-off of fuel injection and spray characteristics with respect to engine crank angle while the fuel injection system was operated by the engine and injecting fuel into the atmosphere.

The effects of varying the engine speed from 400 to 1800 R.P.M., at a constant fuel quantity, and of varying the fuel quantity from approximately one-half load to full load fuel quantity, at a constant engine speed, on the discharge characteristics of an automatic injection valve and fuel injection system were determined. This investigation was conducted at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics.

#### Methods and Apparatus

The general method followed in this investigation was to motor the engine, inject the fuel into a light-tight compartment equipped with an air scavenging system (Figs. 1 and 2), and observe the spray as illuminated by an oscilloscope. Crank angles in degrees were noted for the spray start, for critical points in the injection cycle, and for the spray cut-off for a constant engine speed of 1600 R.P.M. with variable fuel quantity from about one-half to full load fuel quantity, and for a constant fuel quantity of 0.00025 lb. per cycle and engine speeds from 400 to 1800 R P.M.

The engine used was a single cylinder test engine having a 5-inch bore and a 7-inch stroke. The fuel pump was a cam-operated, impact type, plunger pump described in Reference 8. This pump supplied fuel to a centrifugal type, spring-loaded, automatic injection valve having a 0.025 inch diameter orifice. The fuel spray produced in the atmosphere with a valve opening pressure of 6000 lb. per sq.in., was a well atomized, cone-shaped spray. The fuel quantity discharged was varied by adjusting the length of the pump plunger stroke. With this type of fuel injection pump any adjustment of the pump plunger stroke changes the time of injection. Since it was desirable to keep the start of the pump plunger stroke at the same point in the engine cycle, it was necessary to vary the angular relation between the pump and the cam for variations in length of the pump plunger stroke. The variation in the start of the pump plunger stroke for changes in the length of the stroke was determined from a calibration of the fuel pump cam obtained by "barring over" the engine.

The oscilloscope, shown in the photographs of Figures 1 and 2 and as diagrammatically sketched in Figure 3, contained a primary electric circuit with a mechanical circuit breaker and a secondary circuit with a neon lamp. The current source was a 6-volt storage battery from which the current passed through a knife switch, a circuit breaker shunted by a 2 microfarad condenser, and then through the primary of an induction coil. The breaker mechanism was operated by an extension of the engine cam

shaft so that once each engine cycle the primary circuit was broken. The high voltage induced in the secondary of the induction coil caused a discharge of current through the neon lamp which produced a flash of light of short duration. The rapid repetition of these light flashes illuminated successive fuel sprays at progressive points in the development of the spray and produced an image of a single spray when viewed by an observer. At the time the primary circuit was broken, the angular position of the breaker mechanism with relation to the engine crank angle was indicated by a pointer and a calibrated sector of the phase changing disc. The timing of the breaker mechanism was varied by means of a worm and gear, one turn of the hand crank on the worm being equal to 1.2 engine crank degrees.

An observer watched the sprays produced in the light-tight compartment and indicated the direction and amount which an assistant should vary the phase of the fuel spray image. With this method the observer could cause the spray image to slowly approach a point in the spray cycle, such as cut-off, to pass through the point or remain stationary while observations were made of the fuel spray at the time of the event.

### Results and Discussion

The spray observed at the start of injection was light and required from two to five crank degrees to develop into a well-defined, cone-shaped spray. The first part of the spray became

heavier until a definite condition was observed that indicated the start of heavy spray. A few degrees before the fuel cut-off, the spray became less dense, but the cut-off was sharply defined with a distinct gap separating the apex of the spray cone from the fuel valve nozzle. For the tests at constant R.P.M., the start of heavy spray was recorded, as the spray cycle was traversed, at what appeared to be a bursting point, i.e., the entire spray image became suddenly very bright due to the large amount of light reflected by the increased density of the atomized fuel spray. This bursting point could not be detected at engine speeds of less than 1200 R.P.M., but the start of the heavy spray was a distinct point in the fuel spray cycle for all engine speeds from 400 to 1800 R.P.M.

The effect of fuel quantity on the time of spray start and cut-off and the spray bursting point is shown in Figure 4. As the fuel quantity was increased from about one-half load to full load fuel quantity at a constant engine speed of 1600 R.P.M., the injection lag remained constant while the duration of the light spray and total duration of injection increased.

It may be noted in Figure 4, that the injection of fuel actually started 7 degrees before the cam follower should have contacted with the pump plunger. The oscilloscope was used to observe the fuel pump actuating mechanism and it was found that a small irregularity in the pump cam contour which ordinary inspection had failed to reveal, caused the cam follower to leave the



cam and hit the pump plunger. As the cam follower vibrated between the plunger and the cam it delivered successively stronger blows to the plunger as the cam advanced and caused the plunger to lift before the cam had rotated far enough to take up the clearance between the follower and the pump plunger. Observations of the cam follower were made with the oscilloscope at 800 R.P.M. and at gradually increasing engine speeds from 1200 to 1800 R.P.M. The cam follower remained in contact with the cam for an engine speed of 800 R.P.M., but left the cam throughout the range of engine speeds from 1200 to 1800 R.P.M.

The effect of engine speeds from 400 to 1800 R.P.M. on the time during the engine cycle at which spray start and cut-off occurred for a constant fuel quantity of 0.00025 lb. per cycle is shown in Figure 5. The injection lag, in crank degrees, decreased and the duration of injection increased with an increase in engine speed. At engine speeds above 1350 R.P.M., the injection of fuel started before the cam follower should have contacted with the pump plunger.

The events occurring on the fuel injection cycle as determined with the aid of the oscilloscope were definite in most cases. The widest variation in recorded values was noted at the start of injection for low engine speeds where the indistinct start of light spray and less frequent flashes of the neon lamp caused variations in readings of plus or minus 2 degrees.

The oscilloscope may be used to determine the rate of spray

penetration and volume growth in the atmosphere for various engine speeds by measuring the spray travel in crank degrees from the start of injection. The rate of penetration of the fuel spray into dense air may then be obtained by an application of the results obtained with the N.A.C.A. spray photography equipment (Reference 9).

### C o n c l u s i o n s

It was found that for the injection system investigated the injection lag, in crank degrees, decreased with increase in engine speed for a constant quantity of fuel discharged, but was not affected at constant engine speed by varying the fuel quantity from approximately one-half to full load fuel quantity. The duration of injection measured in crank degrees increased with either an increase of engine speed or fuel quantity.

The oscilloscope was easily adapted to permit the investigation of a fuel injection system when operated on an engine and injecting into the atmosphere.

Langley Memorial Aeronautical Laboratory,  
National Advisory Committee for Aeronautics,  
July 27, 1928.

## B i b l i o g r a p h y

- Reference 1. Joachim, W. F. : Oil Spray Investigation of the N.A.C.A. (including Bibliography). (1927) Transactions of the American Society of Mechanical Engineers, Vol. 50, No. 1, O.G.P. 50-6.
- Reference 2. Beardsley, E. G. : The N.A.C.A. Photographic Apparatus for Studying Fuel Sprays from Oil Engine Injection Valves and Test Results from Several Researches. N.A.C.A. Technical Report No. 274. (1927)
- Reference 3. Matthews, Robertson and Gardiner, A. W. : The Time Lag and Interval of Discharge with a Spring-Actuated Fuel Injection Pump. N.A.C.A. Technical Note No. 159. (1923)
- Reference 4. Matthews, Robertson : Discharge Characteristics of a High-Speed Fuel Injection Engine. N.A.C.A. Technical Note No. 213. (1925)
- Reference 5. Schweitzer, P. H. : Discussion of Oil Sprays for Fuel Injection Engines by Means of High-Speed Motion Pictures, by E. G. Beardsley. Transactions of the American Society of Mechanical Engineers, Vol. 50, No. 1, O.G.P. 50-3, p. 7.
- Reference 6. Brown, R. W. : Interesting Instruments Exhibited. The Journal of the Society of Automotive Engineers, Feb., 1928, Vol. 22, No. 2, pp. 284-286.
- Reference 7. : Editorial. The Elverson Oscilloscope. Engineering, Dec. 8, 1922, Vol. 114.

### Bibliography (Cont.)

- Reference 8. Paton, C. R. : Power Output and Air Requirements  
and : of a Two-Stroke Cycle Engine for  
Kemper, Carlton : Aeronautical Use. N.A.C.A. Tech-  
nical Report No. 239. (1926)
- Reference 9. Joachim, W. F. : The Effect of Fuel and Cylinder  
and : Gas Densities on the Character-  
Beardsley, E. G. : istics of Fuel Sprays for Oil  
Engines. N.A.C.A. Technical  
Report No. 281. (1927)

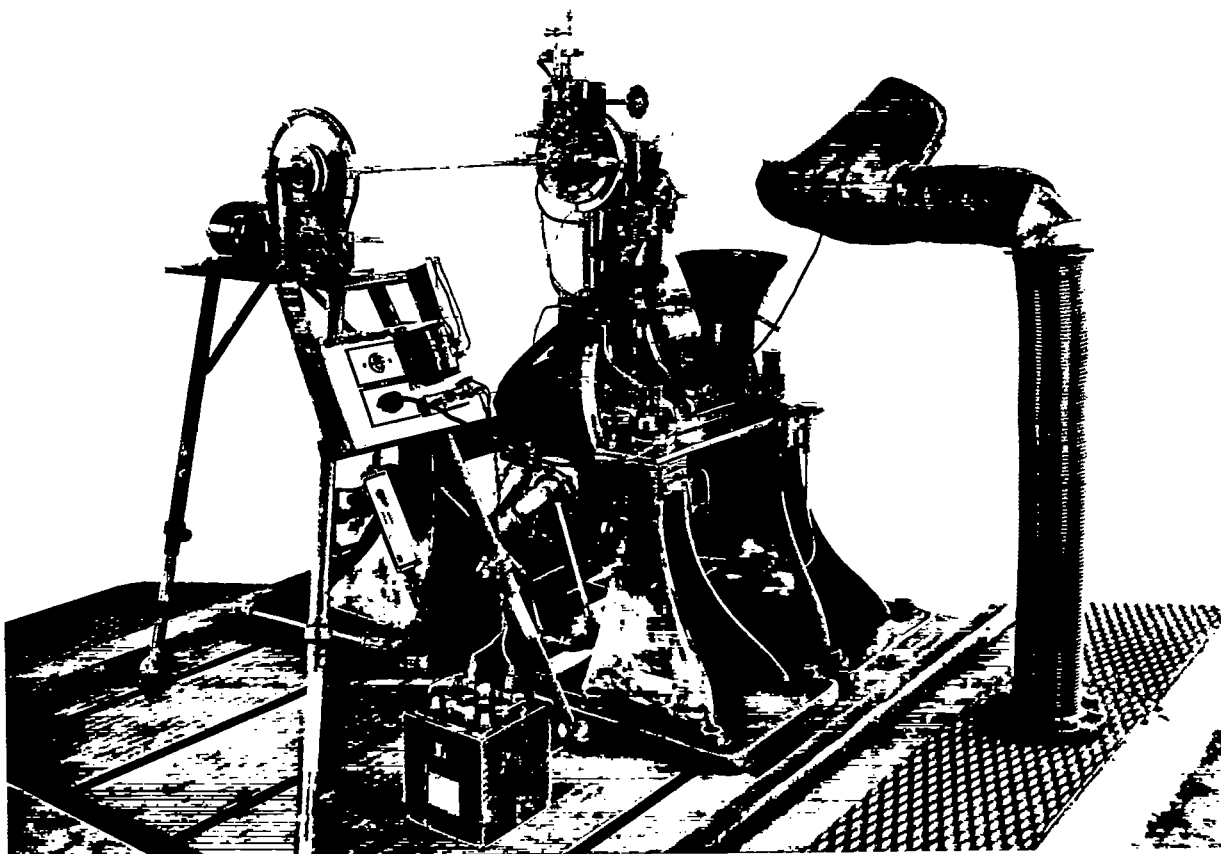


Fig.1 Oscilloscope attached to test engine



Fig.2 Position of injection valve and Neon lamp for observation of fuel sprays.

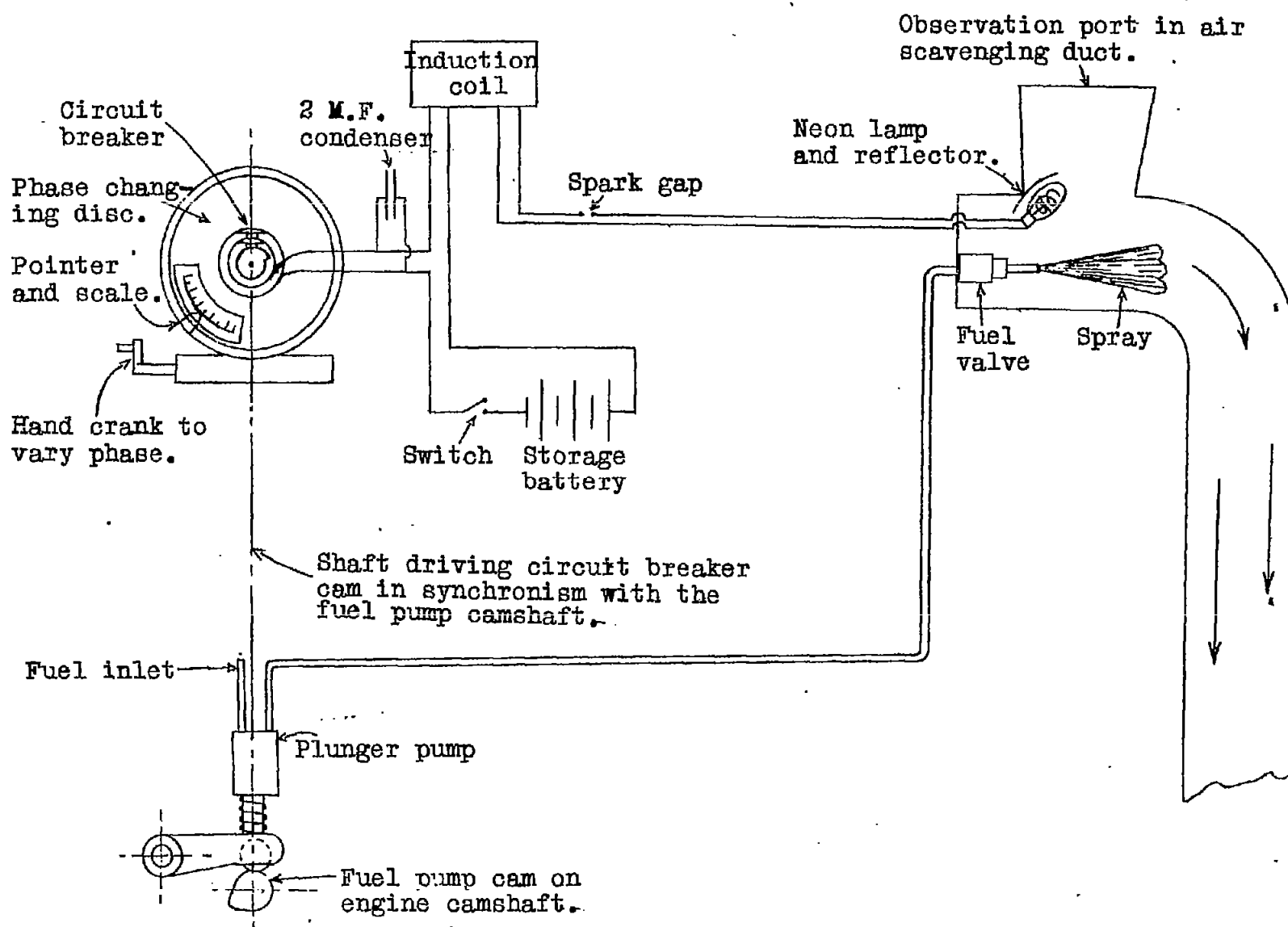


Fig. 3

Fig. 3 Diagrammatic sketch of oscilloscope and fuel injection system.

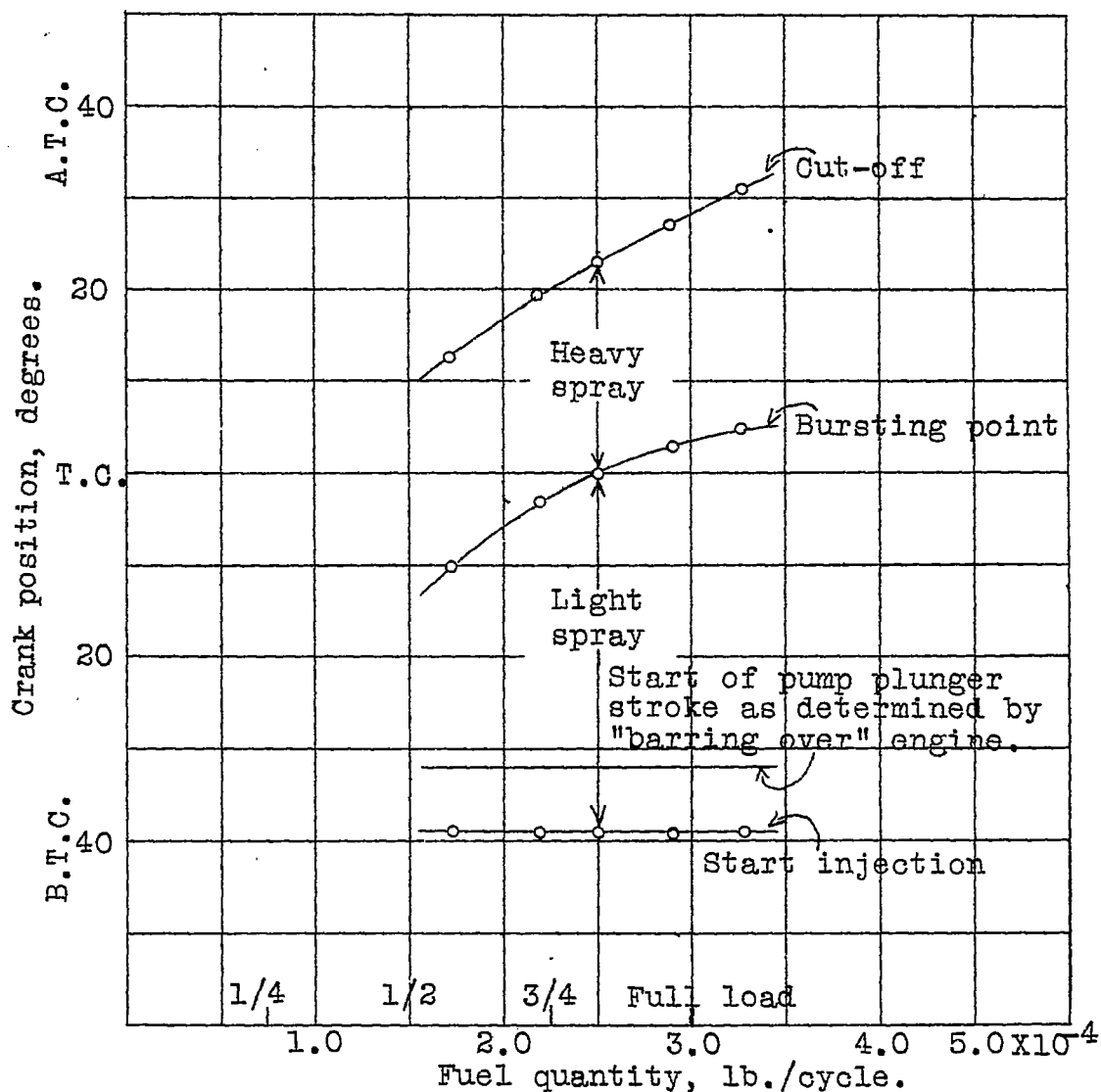


Fig.4 Effect of fuel quantity on injection lag, duration of injection and spray characteristics of an automatic, centrifugal type injection valve. Orifice diameter .025" Valve opening pressure 6000 lb./sq.in. Engine speed, 1600 R.P.M.

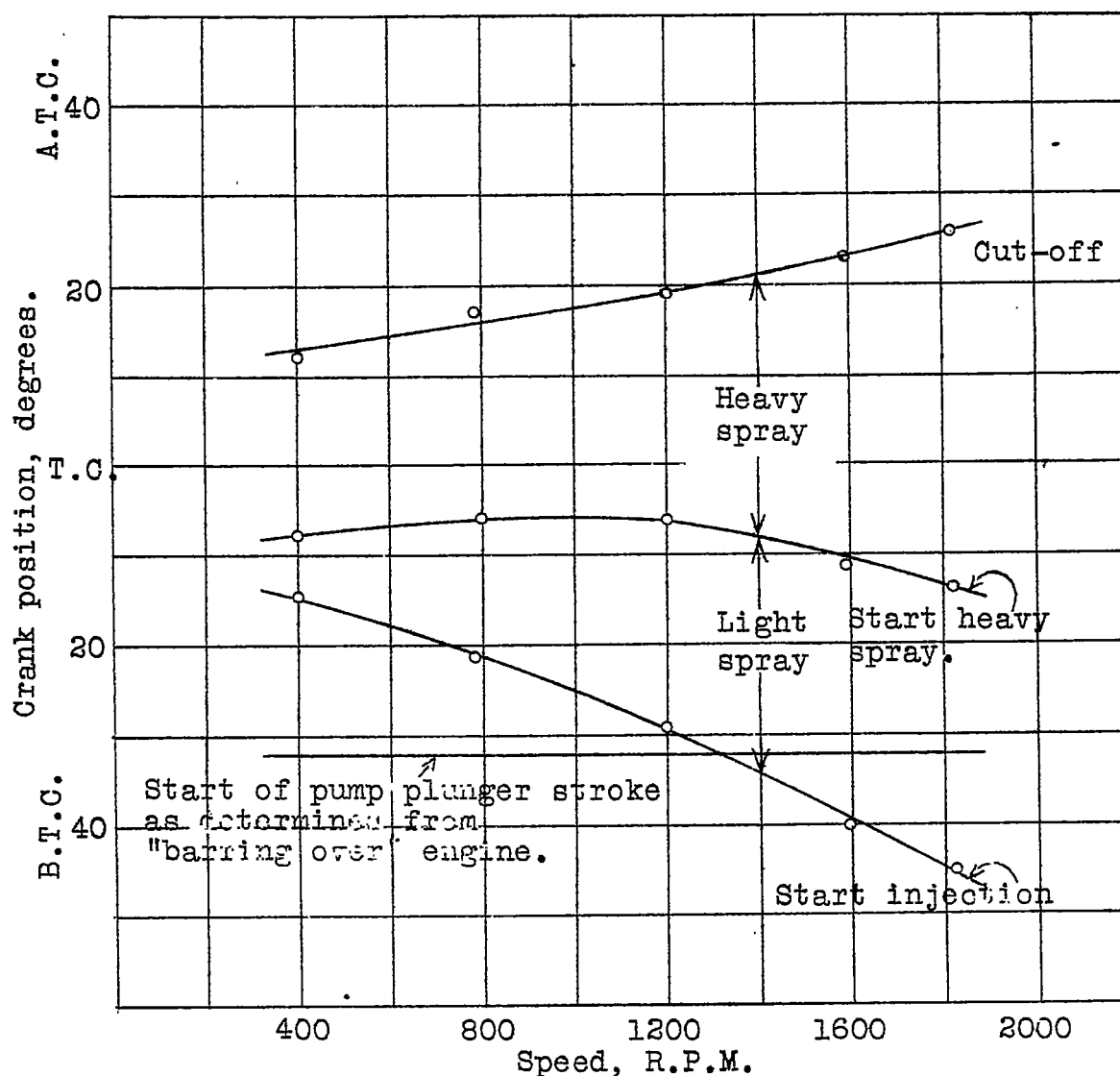


Fig.5 Effect of engine speed on injection lag, duration of injection, and spray characteristics of an automatic, centrifugal type injection valve. Orifice diameter .025" Valve opening pressure 6000 lb./sq.in. Fuel quantity constant at  $2.5 \times 10^{-4}$  lb./cycle.